Observing Gamma-ray Bursts with INTEGRAL

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Abstract. The International Gamma-Ray Astrophysics Laboratory INTEGRAL is dedicated to the fine spectroscopy, and accurate imaging and arcminute location of celestial gamma-ray sources in the energy range 15 keV to 10 MeV. Simultaneous monitoring of the GRB site at X-rays and in the optical V-band will be provided by two on-board monitors. Gamma-ray bursts will be discovered both during routine programme observations as serendipitous sources in the large FOV's and as high resolution time histories from the spectrometer anticoincidence system forming part of the interplanetary network of GRB detectors. The observational capabilities of INTEGRAL further include the dissemination of INTEGRAL GRB alerts and associated data to the science community at large in order to facilitate rapid follow-up observations of GRB error boxes for counterpart searches, afterglow emission and subsequent investigations.

INTRODUCTION

INTEGRAL [8] is ESA's next major 15 keV - 10 MeV gamma-ray mission in collaboration with Russia (PROTON launcher) and NASA (ground stations). The observatory is scheduled for launch in 2001 with a lifetime of two years to up to five years. The scientific objectives focus around high-energy resolution spectroscopy and fine imaging/location of gamma-ray sources and include: study of compact objects; explosive and hydrostatic nucleosynthesis; high energy transients and GRB's; mapping of the Galactic structure (Galactic Centre) and ISM; normal galaxies and clusters; AGN, Blazars and Seyferts; cosmic diffuse background and identification of high energy sources. The payload consists of a Germanium spectrometer (SPI) optimised to perform high-resolution spectroscopy of gamma-ray lines and observations of the large scale diffuse emission, a CdTe/CsI imager (IBIS) optimised to provide fine point source images with accurate locations and sensitive studies of

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continuum and broad lines, and two monitors in the X-ray (JEM-X) and optical energy range (OMC) which identify and monitor high energy sources at the low end of the INTEGRAL energy band. All instruments onboard INTEGRAL are co-aligned with overlapping FOV's and they operate simultaneously. The three high energy instruments utilize coded aperture masks. A particle radiation monitor complements the payload. The key features of the instruments are shown in Table 1. INTEGRAL[2] will be launched in 2001 by a Russian PROTON launcher into a High Earth Orbit (72^h period, 10 000 km (initial) perigee, 153 000 km (initial) apogee, 51.6° inclination) allowing to operate the science instruments entirely outside the Earth's trapped proton belt, and largely outside the electron belts. Nominally, the orbit above 40 000 km altitude (90% of orbital time) will be used for real-time scientific observations (downlink science data-rate = 86 kbps).

GRB DETECTIONS AND OBSERVATIONS

From the scientific objectives and the instrument characteristics in Table 1 it follows that GRB's are one important scientific objective for INTEGRAL, but the payload is not specifically designed to support primarily a GRB mission. However, INTEGRAL is well suited to provide important new observational data on the GRB phenomenon. In particular, INTEGRAL will provide GRB locations to arcminute accuracy or better, spectral coverage from 3 keV (JEM-X) up to 10 MeV (IBIS, SPI) with concurrent optical monitoring and high resolution spectroscopy (2 keV FWHM @ 1.33 MeV). Recent observations of optical, X-ray and radio counterparts, as discussed during this Symposium, show, as expected, that major progress in understanding the GRB phenomenon comes from accurate locations, broad band coverage and rapid response.

High energy detections and optical follow-up (on-board)

SPI, IBIS and JEM-X would detect GRB's in their nominal operational modes (on–ground, photon–by–photon events). The expected number of GRB's per year detected within the fully coded field of view has been estimated to 13 (SPI), about 6 to 24 (IBIS) – where the lower and upper limits are given by the BATSE detection rate and extrapolation of the BATSE lgN/lgP distribution [6] – and 2 to 6 (JEM-X). IBIS will be able to locate GRB's with its upper CdTe detector area (2621 cm^2) to $< 30''$ (Table 1). The IBIS GRB location will be determined on-ground (Figure 1) at the INTEGRAL Science Data Centre [1], [4] from the near real-time data. Then the source position for the optical monitor OMC is calculated and the CCD co-ordinates are automatically uplinked to the OMC instrument. This automatic procedure allows to center a new (previously unknown) CCD read-out window of

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[2]) Further details on INTEGRAL can be found in [8] and http://astro.estec.esa.nl/SA-general/Projects/Integral/integral.html

TABLE 1. Key parameters of the INTEGRAL scientific payload.

	SPI	IBIS	JEM-X	OMC
Energy range	20 keV - 8 MeV	15 keV - 10 MeV	3 keV - 35 keV	500 nm - 600 nm
Detector area (cm^2)	500	2600 (CdTe) 3100 (CsI)	1000 (2 units each 500)	CCD (2048×1024 pxl)
Spectral resolution (FWHM, keV)	2 @ 1.3 MeV	7 @ 100 keV 60 @ 1 MeV	1.5 @ 10 keV	–
Field of view (fully coded)	16°	9° x 9°	4.8°	5.0° x 5.0°
Angular resolution	2° FWHM	12′ FWHM	3′ FWHM	17.6″/pixel
10σ source location	20′	< 0.5′	< 20″	< 8″
Continuum sensitivity[a]	7×10^{-8} @ 1 MeV	4×10^{-7} @ 100 keV	1×10^{-5} @ 6 keV	19.7^{m_v} (3σ, 10^3 s)
Line sensitivity[b]	5×10^{-6} @ 1 MeV	1×10^{-5} @ 100 keV	2×10^{-5} @ 6 keV	–
Timing accuracy (3σ)	100 μs	67μs – 1000 s	128 μs	> 1s

[a] Units are (ph cm^{-2} s^{-1} keV^{-1}) for 3σ detection in 10^6 s.
[b] Units are (ph cm^{-2} s^{-1}) for 3σ detection in 10^6 s.

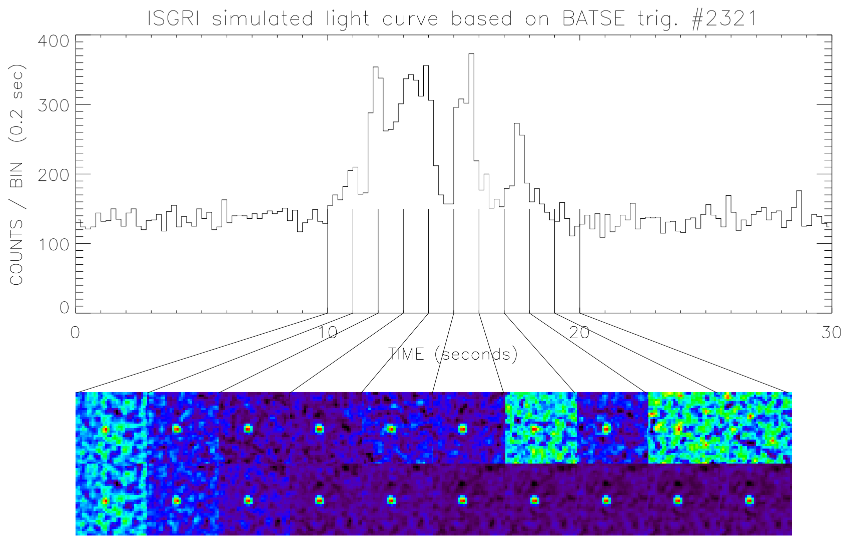

FIGURE 1. Simulated GRB in the IBIS (CdTe array ISGRI) fully coded FOV according to [4]. Photon arrival times are generated based on a BATSE light curve. The peak flux is 0.85 ph/(cm^2s) (50-300 keV) and a double power law spectrum is assumed (α = -0.7 and E_{break} = 100 keV). The upper row displays 15-300 keV images of 1 s integration each, while the images in the lower row are for increasingly longer time intervals (from 1 s to 10 s). With a monitoring in 50 ms time bins and a threshold at 7σ, this GRB triggered at T = 11.7 s. Less than 2 s later, the peak in the deconvolved image (third image from left in bottom row) has reached a S/N of $\sim$ 20.

the OMC rapidly (few seconds up to $\sim$ minute) on the GRB position to allow for near simultaneous optical observation of the GRB event and its possible afterglow.

Studies of afterglow emission

Routine INTEGRAL observations (target pointings of up to typically 14 days) allow in principle the observation of pre- and post-GRB emission in γ-, X-ray and optical domains. Due to specific requirements by the SPI instrument to improve its coded mask imaging, the spacecraft will perform, during many pointings, a number (7 – 25) of small (2°) dithering steps around the nominal target position along a hexagonal or rectangular pattern. This increases the effective sky area viewed by the instruments considerably. Quiescent or afterglow counterparts can therefore be captured during nominal target pointings. Alternatively the spacecraft can react to GRB's outside it's FOV through the standard Target of Opportunity mechanism which allows a re-scheduling of the observing programme and re-pointing of the spacecraft on average within ~30 hours. It is noted that INTEGRAL will perform, as part of its Core Programme [9], weekly scans of a b = ± 20° wide strip along the entire Galactic plane to detect and monitor high energy transients (e.g. GRS 1915+105 etc.), and GRB's would be covered due to their spatial and temporal serendipity. The prospects for observing the fading counterpart with INTEGRAL are promising: X-ray afterglow data for 4 GRB counterparts in 1997 indicate a generic $t^{-1.1}$ decay curve up to 10^6 s after the event. IBIS and JEM-X would have sufficient sensitivity to discover afterglow emission on ~ mCrab level up to about one hour after the event (Figure 2, [7]).

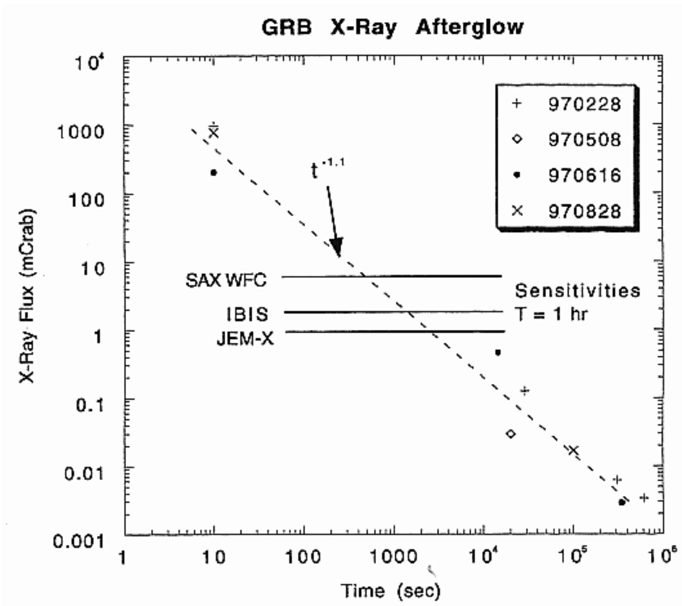

FIGURE 2. INTEGRAL (IBIS/JEM-X) sensitivity to GRB afterglow emission.

Data for GRB arrival time analysis

INTEGRAL will also use the SPI anticoincidence subsystem [2] to provide GRB event time histories (50 ms binning, E > 100 keV) for $\sim$ 350 GRB's/year (10σ, 4π FOV) contributing to the 4th Interplanetary Network (IPN). A GRB event of moderate strength would produce a typcial annulus width of $\sim 7''$, assuming Ulysses at a distance of 4.3 AU. These SPI provided GRB time series would be made available to subscribers of the INTEGRAL GRB alert system described below.

INTEGRAL GRB ALERTS AND THE SCIENTIFIC COMMUNITY

Following the successful utilisation of the BACODINE/GCN network it is planned to implement a similar GRB alert system for INTEGRAL as described in detail by [5]: Its purpose is to faciliate rapid follow-up observations. Based on INTEGRAL detections, a largely automatic system at the INTEGRAL Science Data Centre (ISDC, [1]) in Geneva monitors the real–time telemetry in order to detect, localize and validate an event before an alert is distributed to the community within seconds after the GRB onset. The disseminations of various alerts (as a function of time) will contain increasingly more improved data on the location accuracy: the GRB location accuracy depends on GRB detections performed during (i) spacecraft slews (predicted pointing $\sim 10'$ using slew path simulator); (ii) at start of a stable pointing (predicted position based on previous slew, i.e. $\sim 30''$ for $\leq 2^\circ$ slews and $\sim 5'$ for $\geq 2^\circ$ slews); and (iii) from 10 minutes after start of stable pointing until the end of stable pointing (on-ground attitude reconstitution $\leq 30''$).

Dissemination of alerts are expected to occur in the few seconds to minutes timeframe (see above), and we note that a significant number of GRB's, as deduced from the BATSE 3B distribution of durations [3], has durations longer than 14 s.

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